PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark Office, PCT
2011 South Clark Place Room CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 29 June 2001 (29.06.01)	
International application No. PCT/ZA00/00181	**Applicant's or agent's file reference** F15388/SCF
International filing date (day/month/year) 05 October 2000 (05.10.00)	**Priority date** (day/month/year) 05 October 1999 (05.10.99)
Applicant CILLIERS, Bartolomomeus, Johannes, Le Roux et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   03 May 2001 (03.05.01)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was / [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Tewfik Benyahia (Fax 338.87.40) Telephone No.: (41-22) 338.83.38

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REC'D 18 MAR 2002

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PATENT COOPERATION TREATY

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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference F15388/SCF	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/ZA00/00181	International filing date *(day/month/year)* 05/10/2000	Priority date *(day/month/year)* 05/10/1999
International Patent Classification (IPC) or national classification and IPC G01L3/10		
Applicant CILLIERS, Bartolomomeus, Johannes, Le, Roux		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 12 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☐ Certain defects in the international application
   VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
03/05/2001	06.03.2002
Name and mailing address of the international preliminary examining authority: European Patent Office - P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk - Pays Bas Tel. +31 70 340 - 2040 Tx: 31 651 epo nl Fax: +31 70 340 - 3016	Authorized officer Zafiropoulos, N Telephone No. +31 70 340 3078

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

2,4,6,8-12	as originally filed	
1,1a,3,5,7	with telefax of	02/02/2002

Claims, No.:

1-35	with telefax of	02/02/2002

Drawings, sheets:

1/2,2/2	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☒ the claims, Nos.: 36
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-35
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-35
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-35
	No:	Claims	

2. Citations and explanations
   see separate sheet

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

Reference is made to the following document:

D: WO 96 20395 A (SIEMENS AG ;GLOGER MEINRAD (DE)) 4 July 1996 (1996-07-04)

1) The document D is regarded as being the closest prior art for the subject-matter of claim 1 and discloses: A process for determining a power output rate between a rotary shaft and one or more stationary machines connected to the shaft. The torsional deformation of the shaft is measured as an angle (see page 6).

The subject-matter of claim 1 differs from this known from D in that: A datum time period between a datum time moment a datum point 52 (see fig.2) passes a stationary station and a time moment the measure point 42 passes a stationary measure station is established under no load and load conditions and rotational speed of the shaft is recorded under these conditions. The length of the shaft is established over which torque is applied and the twist of the shaft is calculated on the basis of the difference between the measured time period and the datum time period under consideration of the measured speed and the length of the shaft over which torque is applied.

This method is more precise than the method of the prior art and takes additionally the length of the length of the shaft over which torque is applied into account. Therefore

this claim is new and inventive (Art. 33(2), (3) PCT).

2) The claims 2 to 13, which include further details of the method, are also new and inventive (Art. 33(2), (3) PCT) as they are dependent from claim 1.

3) In independent claim 14 the measured time period is compared with a computed time period under no load conditions. This is the difference to independent claim 1. Compared to D this claim is new and inventive (Art. 33(2), (3) PCT).

4) Claim 15 is dependent on claim 14 and therefore new and inventive.

5) Independent claim 16 describes the apparatus for implementing the method of claim 1. This apparatus includes a processor programmed to fulfil the method steps of claim 1. The same comments with respect to D also apply to the apparatus. This claim is new and inventive (Art. 33(2), (3) PCT).

6)The claims 17-35 are dependent on claim 16 and also new and inventive (Art. 33(2),(3) PCT).

10/089747
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WO 01/25738 PCT/ZA00/00181

2/PRTS

MEASURING TWIST DUE TO TORQUE IN A ROTATING SHAFT

THIS INVENTION relates to m asuring twist du to torque in a rotating shaft. It relates more specifically to a method of and measuring apparatus for measuring twist in a rotating shaft subjected to torque, to a method of and a measuring apparatus for measuring torque in a rotating shaft, and to a method of and an apparatus for managing operation of an engine.

The term "twist" is for convenience used for purposes of this invention to denote angular deflection or angular deformation.

In accordance with a first aspect of this invention, broadly, there is provided a method of measuring twist in a rotating shaft which is subjected to torque including sensing an arrival time moment of a measure point on the shaft at a fixed measure station, comparing the arrival time moment with a computed arrival time moment of said measure point at said measure station under a no load condition, measuring rotational speed of the shaft, and calculating the twist in th shaft on the basis of the time lag and the rotational speed.

The method may include sensing and recording a datum time moment when a datum point on the shaft, longitudinally spaced from said measur point by a predetermined distance, passes a fixed datum station, and measuring a measure time period between said datum time moment and said arrival time moment.

The method may include empirically predetermining a datum time period between a datum time moment and an arrival time moment under a no load condition at a determined rotational speed, and computing a computed time period and a computed arrival time moment for any specific rotational speed on the basis of the datum time period bearing in mind the respective rotational speeds.

In accordance with the first aspect of this invention, more specifically, there is provided m thod f measuring twist in a rotating shaft which is subj ct d to torque, betwe n a datum p int on the shaft and a measur p int on the shaft longitudinally spaced from th datum point, the m thod including

establishing a datum time period betwe n a datum time moment the datum

reciprocating internal combustion engine.

In another technical application, the method may b applied to a gas turbine engine, the shaft then being a main shaft of the gas turbine engine.

Then, at least one of the datum point and the measure point may be on a vane of at least one of a compressor and a turbine of the gas turbine engine. However, the method is preferably preformed in respect of a plurality of measure points and a plurality of datum points, the plurality of measure points being on a corresponding plurality of vanes of one of the compressor and the turbine and the plurality of datum points being on a corresponding plurality of vanes of the other of the compressor and the turbine, the sensors being external of casings surrounding respectively the compressor and the turbine.

Generally, establishing the time moments may include triggering a sensor at respectively the datum station and the measure station by means of triggers at correspondingly the or each datum point and the or each measure point, creating a signal by each sensor and recording the signal against time.

The triggers may be masses of magnetic material, and the sensors may be responsive to said magnetic material to create said signals.

Instead, the triggers may be optically detectable surfaces, the sensors then sensing passing of the triggers optically.

In accordance with a second aspect of this invention, there is provided measuring apparatus for measuring twist in a rotating shaft which is subjected to torque, the measuring apparatus including

at least one datum trigger at a datum point on the shaft;

a datum sensor at a stationary datum station arranged to sense said at least one datum trigger when said at least one datum point is in register with the datum station and to generate correspondingly at least one datum signal;

at least one m asure trigger at correspondingly at least one measure point n the shaft longitudinally spaced from said at least on datum point;

a measur sensor at a stationary measure station arranged to s ns said at least one measure trigg r when said at least one measure trigg r is in register with

In another technical application, the shaft may be a main shaft of a gas turbine engine. Then, at least one of the datum point and the measure point is on correspondingly at least one of a vane of a compressor and a vane of a turbine of the gas turbine engine. However, the measuring apparatus may include a plurality of datum points and a plurality of measure points, the datum points and the measure points being respectively on vanes of the compressor and the turbine.

The triggers may be masses of magnetic material, and the sensors may be magnetic sensors responsive to said magnetic material to generate signals. The magnetic sensors may be arranged external of casings surrounding respectively the compressor and the turbine.

Instead, the triggers may be optically detectable surfaces, and the sensors may be optical sensors responsive to the optically detectable triggers to generate signals.

In accordance with a third aspect of this invention, there is provided a method of measuring torque in a rotating shaft, including measuring twist in th rotating shaft in accordance with the first aspect of this invention, and calculating torque on the basis of the measured twist bearing in mind a pre-established length of the shaft over which length said twist is measured, and pre-established physical characteristics of the shaft determining torque-twist behaviour of the shaft.

Said physical characteristics of the shaft determining torque-twist behaviour of the shaft may advantageously be established empirically.

In accordance with a fourth aspect of this invention, there is provided a measuring apparatus for measuring torque in a rotating shaft, which includes a measuring apparatus for measuring twist in accordance with the second aspect of this invention, in which the processor is programmed to calculate torque on the basis of the measured twist bearing in mind a pre-established length of th shaft over which length said twist is measured and pre-established physical characteristics of the shaft determining torque-twist b haviour of th shaft.

In accordance with a fifth asp ct of this invention, th re is provided a method of managing op ration of an ngine including m asuring a quantity

The invention will now be described, by way of xamples, with reference to the accompanying diagrammatic drawings.

In the drawings

Figure 1 shows a block diagram of an apparatus for measuring torque in accordance with the invention;

Figure 2 shows, in three dimensional view, the invention applied to a reciprocating internal combustion engine; and

Figure 3 corresponds to Figure 2, but shows a gas turbine engine.

Referring to Figures 1 and 2 of the drawings, reference numeral 10 generally indicates a measuring apparatus in accordance with the invention.

The apparatus 10 measures twist in a drive shaft in the form of a crankshaft 30 (see Figure 2 of the drawings) of a reciprocating internal combustion engine 29. In Figure 2 only the pistons 32 of the engine, and connection of the pistons 32 via connecting rods 34 to cranks of a crankshaft 30 of the engine, are shown.

A flywheel 40 incorporating a ring gear having a plurality of circumferentially spaced teeth 42 is mounted at one end of the crankshaft 30. The flywheel 40 and specifically also the teeth 42 are of a magnetic material. During operation of the engine, thrust of the pistons 32 during power strokes causes twist in the crankshaft 30.

In order to measure said twist, the measuring apparatus 10 includes a circular metallic disc 50 secured to the end of the crankshaft 30 opposite the flywheel 40. The disc 50 has a plurality of formations or teeth 52 defining triggers in the form of datum points. The teeth, in this embodiment, are of magnetic material.

The apparatus 10 further includes a sensor in the form of a magnetic s nsor or pick-up devic 12.1, e.g. Part No. 304166 from the RS catalogue, mounted on the engine adjacent a pitch circle of the teeth 52 of th disc so as to be registered sequentially with the t eth as th disc 50 rotat s with the crankshaft 30. Each time a tooth 52 is in register with th sensor 12.1 a signal in the form

CLAIMS

1. A method of measuring twist in a rotating shaft which is subjected to torque including sensing an arrival time moment of a measure point on the shaft at a fixed measure station, comparing the arrival time moment with a computed arrival time moment of said measure point at said measure station under a no load condition, measuring rotational speed of the shaft, and calculating the twist in the shaft on the basis of the time lag and the rotational speed.

2. A method as claimed in Claim 1 which includes sensing and recording a datum time moment when a datum point on the shaft, longitudinally spaced from said measure point by a predetermined distance, passes a fixed datum station, and measuring a measure time period between said datum tim moment and said arrival time moment.

3. A method as claimed in Claim 2 which includes empirically predetermining a datum time period between a datum time moment and an arrival time moment under a no load condition at a determined rotational speed, and computing a computed time period and a computed arrival time moment for any specific rotational speed on the basis of the datum time period bearing in mind the respective rotational speeds.

4. A method of measuring twist in a rotating shaft which is subjected to torque, between a datum point on the shaft and a measure point on the shaft longitudinally spaced from the datum point, the method including

establishing a datum time period between a datum time moment the datum point passes a stationary datum station and a time moment the measure point passes a stationary measure station under a no load condition and recording rotational speed of the shaft as the datum speed;

measuring a measure time period between a time moment the datum point passes the stationary datum station and a time moment the measure point passes the stationary measure station when the shaft is subjected to torque, recording the rotational spe d of the shaft as the measure speed and establishing l ngitudinal positions respectively at which torque is applied and of th datum point and of th measure point;

calculating the twist in the shaft from the differ nc betw en the measur

time period and the datum time period, bearing in mind the difference between the measure spe d and the datum speed.

5. A method as claimed in Claim 4 in which a torque point at which torque is applied to the shaft and a load point at which a load is connected to the shaft are longitudinally spaced, the shaft being stressed and undergoing twist between the torque point and the load point, one of the measure point and the datum point being positioned along said stressed portion of the shaft, the other of the measure point and the datum point being positioned in a relaxed portion of the shaft beyond one of the torque point and the load point.

6. A method as claimed in Claim 5 in which the shaft is a crankshaft of a reciprocating internal combustion engine.

7. A method as claimed in Claim 6 in which the reciprocating engine includes a ring gear having gear teeth at one end of the crankshaft and a disc at an opposed end of the crankshaft, the datum point being on the disc, the measure point being on a gear tooth of the ring gear.

8. A method as claimed in Claim 7 which is performed in respect of a plurality of measure points and a plurality of datum points, the plurality of measure points being on a corresponding plurality of gear teeth of the ring gear and the plurality of datum points being points which are circumferentially spaced on the disc.

9. A method as claimed in Claim 8 in which the reciprocating internal combustion engine includes a plurality of cylinders, the method being performed in respect of each cylinder.

10. A method as claimed in Claim 8 or Claim 9 which is performed for each power stroke of the reciprocating internal combustion engine.

11. A method as claimed in Claim 5 in which the shaft is a main shaft of a gas turbine ngine.

12. A method as claimed in Claim 11 in which at l ast one of the datum

point and the measure point is on a vane of at least one of a compressor and a turbine of the gas turbine engine.

13. A method as claimed in Claim 12 which is preformed in respect of a plurality of measure points and a plurality of datum points, the plurality of measure points being on a corresponding plurality of vanes of one of the compressor and the turbine and the plurality of datum points being on a corresponding plurality of vanes of the other of the compressor and the turbine, the sensors being external of casings surrounding respectively the compressor and the turbine.

14. A method as claimed in any one of claim 4 to Claim 13 inclusive in which establishing the time moments includes triggering a sensor at respectively the datum station and the measure station by means of triggers at correspondingly the or each datum point and the or each measure point, creating a signal by each sensor and recording the signal against time.

15. A method as claimed in Claim 14 in which the triggers are masses of magnetic material, and the sensors are responsive to said magnetic material to create said signals.

16. A method as claimed in Claim 14 in which the triggers are optically detectable surfaces, and the sensors sense passing of the triggers optically.

17. A measuring apparatus for measuring twist in a rotating shaft which is subjected to torque, the measuring apparatus including

at least one datum trigger at a datum point on the shaft;

a datum sensor at a stationary datum station arranged to sense said at least one datum trigger when said at least one datum point is in register with the datum station and to generate correspondingly at least one datum signal;

at least one measure trigger at correspondingly at least one measure point on the shaft longitudinally spaced from said at least one datum point;

a measur sensor at a stationary m asure station arranged to sense said at least one measure trigg r when said at least one measure trigg r is in register with the measure station and to gen rate correspondingly at least one measur signal;

a clock keeping tim ;

a rotational speed meter for measuring and recording rotational speeds of the shaft against time respectively as the datum speed and as the measure speed;

recording m ans for recording said datum and measure signals against time;

a processor programmed to establish

correspondingly at least one datum time period between a time moment said at least one datum point passes the datum station and a time moment said at least one measure point passes the measure station under no load conditions and recording the rotational speed of the shaft as the datum speed,

correspondingly at least one measure time period between a time moment said at least one datum point passes the stationary datum station and a time moment said at least one measure point passes the stationary measure station when the shaft is subjected to torque and recording the rotational speed of the shaft as the measure speed, and

the twist of the shaft from the difference between said at least one measure time period and said at least one datum time period, bearing in mind the ratio between the measure speed and the datum speed.

18. A measuring apparatus as claimed in Claim 17 in which the shaft includes a torque point at which torque is applied to the shaft in use and a load point at which a load is connected to the shaft in use, the torque point and the load point being longitudinally spaced, the shaft, in use, being stressed and undergoing twist between the torque point and the load point, one of the or each measure point and the or each datum point being positioned along said stressed portion of the shaft, the other of the or each measure point and the or each datum point being positioned in a relaxed portion of the shaft beyond one of the torque point and the load point.

19. A measuring apparatus as claimed in Claim 18 in which the shaft is a crankshaft of a reciprocating internal combustion engine.

20. A measuring apparatus as claimed in Claim 19 which includes a plurality of measure points and a plurality of datum points.

21. A m asuring apparatus as claimed in Claim 20 in which the r ciprocating engin includes a ring gear having gear t eth at ne end of the crankshaft and a disc at an oppos d end of the crankshaft, the datum points and

the measuring points being respectively on gear teeth of the ring g ar and at circumferentially spaced positions on the disc.

22. A measuring apparatus as claimed in Claim 18 in which the shaft is a main shaft of a gas turbine engine.

23. A measuring apparatus as claimed in Claim 22 in which at least one of the datum point and the measure point is on correspondingly at least one of a vane of a compressor and a vane of a turbine of the gas turbine engine.

24. A measuring apparatus as claimed in Claim 23 which includes a plurality of datum points and a plurality of measure points, the datum points and the measure points being respectively on vanes of the compressor and the turbine.

25. A measuring apparatus as claimed in any one of Claim 17 to Claim 24 inclusive in which the triggers are masses of magnetic material, and the sensors are responsive to said magnetic material to generate signals.

26. A measuring apparatus as claimed in Claim 25 in which the sensors are in the form of magnetic sensors arranged external of casings surrounding respectively the compressor and the turbine.

27. A measuring apparatus as claimed in any one of Claim 17 to Claim 24 inclusive in which the triggers are optically detectable surfaces, and the sensors are optical sensors responsive to the optically detectable triggers to generate signals.

28. A method of measuring torque in a rotating shaft, including measuring twist in the rotating shaft in accordance with any one of Claim 1 to Claim 16 inclusive, and calculating torque on the basis of the measured twist bearing in mind a pre-established length of the shaft over which length said twist is measured, and pre-established physical characteristics of the shaft determining torque-twist b haviour of the shaft.

29. A m th d as claimed in Claim 28 in which said physical characteristics of the shaft d t rmining torqu -twist behaviour of the shaft are

established empirically.

30. A measuring apparatus for m asuring torque in a rotating shaft, which includ s a measuring apparatus for measuring twist as claimed in any one of Claim 17 to Claim 27 inclusive, in which the processor is programmed to calculate torque on the basis of the measured twist bearing in mind a pre-established length of the shaft over which length said twist is measured and pre-established physical characteristics of the shaft determining torque-twist behaviour of the shaft.

31. A method of managing operation of an engine including measuring a quantity related to torque in a drive shaft of the engine as claimed in any one of Claim 1 to Claim 16 or Claim 28 or Claim 29, comparing the measured value of said quantity related to torque to a predetermined standard value of said quantity, establishing any deviation between the measured value and the standard value and controlling an operating function of the engine in response to said establish deviation.

32. A method as claimed in Claim 31 in which said operating function of the engine is at least one of ignition timing when the engine is a spark ignition engine, injector pump timing when said engine is a diesel engine, boost pressur when said engine is turbocharged or supercharged.

33. A method as claimed in Claim 31 or Claim 32 including automatically calibrating the measuring apparatus in respect of datum time periods when th engine is operated under a no load condition.

34. An engine including

a measuring apparatus as claimed in any one of Claim 17 to Claim 27 or claim 30;

an engine management apparatus including a comparator arranged to receive a signal indicative of a measured value of a quantity related to torque in a drive shaft of the engine from the measuring apparatus, the comparator being pr programmed to compare said measured value with a standard valu of said quantity related to torque to gen rate a control signal, th ngine management apparatus being responsive to said control signal to control an operating function

of the engine.

35. An ngine as claimed in Claim 34 in which said operating function of the engine is at least one of ignition timing when the engine is a spark ignition engine, injector pump timing when said engine is a diesel engine, boost pressure when said engine is turbocharged or supercharged.

36. An engine as claimed in Claim 34 or Claim 35 in which the engine management apparatus is preprogrammed to calibrate the measuring apparatus in respect of datum time periods when the engine is operated under a no load condition.

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Published:
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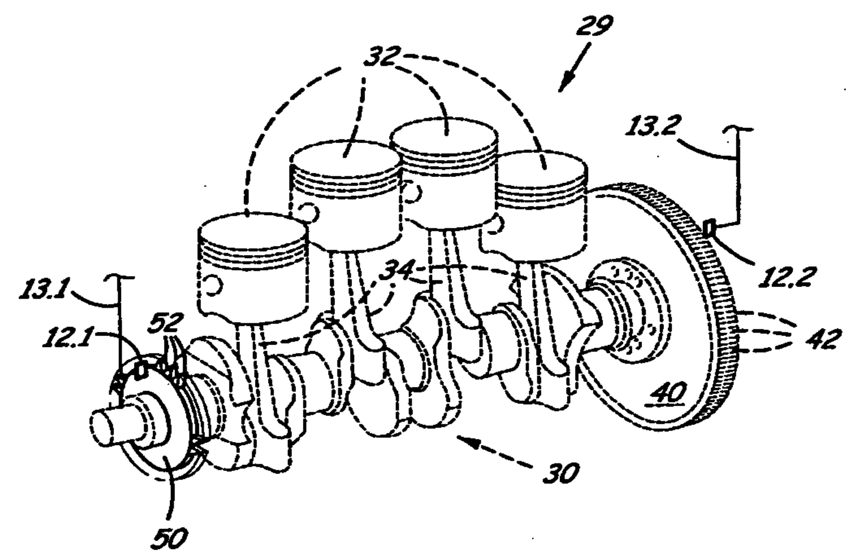
For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: MEASURING TWIST DUE TO TORQUE IN A ROTATING SHAFT



(57) Abstract: In a reciprocating engine, power strokes of pistons (32) apply torque to a crankshaft (30) causing it to twist proportionally. Datum time moments are established by triggers (52) rotating with, at one end of, the crank shaft and a sensor (12.1) sensing passing of the triggers. At an opposed end, ring gear teeth (42) trigger a sensor (12.2). At no load, zero twist occurs and arrival time moments of the triggers (42) in relation to the datum time moments are predictable. Under load, twisting in the crank shaft causes the arrival time moments to be delayed, the time lag being proportional to the twist, bearing in mind the effect of rotational speed. With information about physical twist-torque characteristics of the crankshaft (30), torque values are calculated from the measured twist values, and are used in engine management. The invention can be applied to any shaft, for example also a main shaft of a gas turbine engine.

WO 01/25738 A1

MEASURING TWIST DUE TO TORQUE IN A ROTATING SHAFT

THIS INVENTION relates to measuring twist due to torque in a rotating shaft. It relates more specifically to a method of and measuring apparatus for measuring twist in a rotating shaft subjected to torque, to a method of and a measuring apparatus for measuring torque in a rotating shaft, and to a method of and an apparatus for managing operation of an engine.

The term "twist" is for convenience used for purposes of this invention to denote angular deflection or angular deformation.

In accordance with a first aspect of this invention, broadly, there is provided a method of measuring twist in a rotating shaft which is subjected to torque including sensing an arrival time moment of a measure point on the shaft at a fixed measure station, comparing the arrival time moment with a computed arrival time moment of said measure point at said measure station under a no load condition, measuring rotational speed of the shaft, and calculating the twist in the shaft on the basis of the time lag and the rotational speed.

The method may include sensing and recording a datum tim moment when a datum point on the shaft, longitudinally spaced from said measure point by a predetermined distance, passes a fixed datum station, and measuring a measure time period between said datum time moment and said arrival time moment.

The method may include empirically predetermining a datum time period between a datum time moment and an arrival time moment under a no load condition at a determined rotational speed, and computing a computed time period and a computed arrival time moment for any specific rotational speed on the basis of the datum time period bearing in mind the respective rotational speeds.

In accordance with the first aspect of this invention, more specifically, there is provided m thod of m asuring twist in a rotating shaft which is subj ct d to torque, betw en a datum point on th shaft and a measur point on the shaft longitudinally spaced from th datum point, the method including

establishing a datum time period betwe n a datum time moment th datum

point passes a stationary datum station and a time moment the measure point passes a stationary measure station under a no load condition and recording rotational speed of the shaft as the datum speed;

measuring a measure time period between a time moment the datum point passes the stationary datum station and a time moment the measure point passes the stationary measure station when the shaft is subjected to torque, recording the rotational speed of the shaft as the measure speed and establishing longitudinal positions respectively at which torque is applied and of the datum point and of the measure point;

calculating the twist in the shaft from the difference between the measure time period and the datum time period, bearing in mind the difference between the measure speed and the datum speed.

A torque point at which torque is applied to the shaft and a load point at which a load is connected to the shaft may be longitudinally spaced, the shaft being stressed and undergoing twist between the torque point and the load point, one of the measure point and the datum point being positioned along said stressed portion of the shaft, the other of the measure point and the datum point being positioned in a relaxed portion of the shaft beyond one of the torque point and the load point.

Advantageously, the method may be applied to a shaft in the form of a crankshaft of a reciprocating internal combustion engine. The reciprocating engine may include a ring gear having gear teeth at one end of the crankshaft and a disc at an opposed end of the crankshaft, the datum point being on the disc, the measure point being on a gear tooth of the ring gear. The method is preferably performed in respect of a plurality of measure points and a plurality of datum points, the plurality of measure points being on a corresponding plurality of gear teeth of the ring gear and the plurality of datum points being points which are circumferentially spaced on the disc. Advantageously, the number of datum points and the number of measure points may be equal, to allow the respective datum points and measure points to be associated on a one-on-one basis.

Wh n th reciprocating internal combustion engine includ s a plurality of cylinders, th meth d may be performed in resp ct of each cylinder. Furthermore, the method may b performed for ach power stroke of the

reciprocating internal combustion engine.

In another technical application, the method may be applied to a gas turbine engine, the shaft then being a main shaft of the gas turbine engine.

Then, at least one of the datum point and the measure point may be on a vane of at least one of a compressor and a turbine of the gas turbine engine. However, the method is preferably preformed in respect of a plurality of measure points and a plurality of datum points, the plurality of measure points being on a corresponding plurality of vanes of one of the compressor and the turbine and the plurality of datum points being on a corresponding plurality of vanes of the other of the compressor and the turbine, the sensors being external of casings surrounding respectively the compressor and the turbine.

Generally, establishing the time moments may include triggering a sensor at respectively the datum station and the measure station by means of triggers at correspondingly the or each datum point and the or each measure point, creating a signal by each sensor and recording the signal against time.

The triggers may be masses of magnetic material, and the sensors may be responsive to said magnetic material to create said signals.

Instead, the triggers may be optically detectable surfaces, the sensors then sensing passing of the triggers optically.

In accordance with a second aspect of this invention, there is provided measuring apparatus for measuring twist in a rotating shaft which is subjected to torque, the measuring apparatus including

at least one datum trigger at a datum point on the shaft;

a datum sensor at a stationary datum station arranged to sense said at least one datum trigger when said at least one datum point is in register with the datum station and to generate correspondingly at least one datum signal;

at least one measure trigg r at correspondingly at least on measure point on the shaft longitudinally spac d from said at least one datum point;

a measure sensor at a stationary measure station arranged to sense said at l ast one measur trigger when said at least one measur trigg r is in register with

the measure station and to generate correspondingly at least one m asure signal;

a clock keeping tim ;

a rotational speed meter for measuring and recording rotational speeds of the shaft against time respectively as the datum speed and as the measure speed;

recording means for recording said datum and measure signals against time;

a processor programmed to establish

correspondingly at least one datum time period between a time moment said at least one datum point passes the datum station and a time moment said at least one measure point passes the measure station under no load conditions and recording the rotational speed of the shaft as the datum speed,

correspondingly at least one measure time period between a time moment said at least one datum point passes the stationary datum station and a time moment said at least one measure point passes the stationary measure station when the shaft is subjected to torque and recording the rotational speed of the shaft as the measure speed, and

the twist of the shaft from the difference between said at least one measure time period and said at least one datum time period, bearing in mind the ratio between the measure speed and the datum speed.

The shaft may include a torque point at which torque is applied to the shaft in use and a load point at which a load is connected to the shaft in use, the torque point and the load point being longitudinally spaced, the shaft, in use, being stressed and undergoing twist between the torque point and the load point, one of the or each measure point and the or each datum point being positioned along said stressed portion of the shaft, the other of the or each measure point and the or each datum point being positioned in a relaxed portion of the shaft beyond one of the torque point and the load point.

The shaft may advantageously be a crankshaft of a reciprocating internal combustion engine. Then the measuring apparatus may preferably include a plurality of measure points and a plurality of datum points.

Advantageously, the reciprocating engine may include a ring gear having g ar teeth at one end of the crankshaft and a disc at an opposed end of th crankshaft, th datum points and the measuring points b ing r sp ctively on gear t eth of th ring g ar and at circumferentially spaced positions on the disc.

In another technical application, the shaft may be a main shaft of a gas turbine engine. Then, at least one of the datum point and the measure point is on correspondingly at least one of a vane of a compressor and a vane of a turbine of the gas turbine engine. However, the measuring apparatus may include a plurality of datum points and a plurality of measure points, the datum points and the measure points being respectively on vanes of the compressor and the turbine.

The triggers may be masses of magnetic material, and the sensors may be magnetic sensors responsive to said magnetic material to generate signals. The magnetic sensors may be arranged external of casings surrounding respectively the compressor and the turbine.

Instead, the triggers may be optically detectable surfaces, and the sensors may be optical sensors responsive to the optically detectable triggers to generate signals.

In accordance with a third aspect of this invention, there is provided a method of measuring torque in a rotating shaft, including measuring twist in the rotating shaft in accordance with the first aspect of this invention, and calculating torque on the basis of the measured twist bearing in mind a pre-established length of the shaft over which length said twist is measured, and pre-established physical characteristics of the shaft determining torque-twist behaviour of the shaft.

Said physical characteristics of the shaft determining torque-twist behaviour of the shaft may advantageously be established empirically.

In accordance with a fourth aspect of this invention, there is provided a measuring apparatus for measuring torque in a rotating shaft, which includes a measuring apparatus for measuring twist in accordance with the second aspect of this invention, in which the processor is programmed to calculate torque on the basis of the measured twist bearing in mind a pre-established length of the shaft over which length said twist is measured and pre-established physical characteristics of the shaft determining torque-twist behaviour of the shaft.

In accordanc with a fifth aspect of this invention, there is provided a method of managing operation of an engine including m asuring a quantity

related to torque in a drive shaft of the engine in accordance with the first aspect or the third aspect of this invention, comparing the measured value of said quantity related to torque to a predetermined standard value of said quantity, establishing any deviation between the measured value and the standard value and controlling an operating function of the engine in response to said establish deviation.

Said operating function of the engine may be at least one of ignition timing when the engine is a spark ignition engine, injector pump timing when said engine is a diesel engine, boost pressure when said engine is turbocharged or supercharged.

Advantageously, the method may include automatically calibrating the measuring apparatus in respect of datum time periods when the engine is operated under a no load condition.

In accordance with a sixth aspect of this invention, there is provided an engine including

a measuring apparatus in accordance with the second aspect or the fourth aspect of this invention;

an engine management apparatus including a comparator arranged to receive a signal indicative of a measured value of a quantity related to torque in a drive shaft of the engine from the measuring apparatus, the comparator being preprogrammed to compare said measured value with a standard value of said quantity related to torque to generate a control signal, the engine management apparatus being responsive to said control signal to control an operating function of the engine.

Said operating function of the engine may be at least one of ignition timing when the engine is a spark ignition engine, injector pump timing when said engine is a diesel engine, boost pressure when said engine is turbocharged or supercharged.

Advantag ously, the ngine manag ment apparatus may be preprogrammed to calibrate th measuring apparatus in respect of datum tim p riods wh n th engine is operat d under a no load condition.

The invention will now be described, by way of examples, with reference to the accompanying diagrammatic drawings.

In the drawings

Figure 1 shows a block diagram of an apparatus for measuring torque in accordance with the invention;

Figure 2 shows, in three dimensional view, the invention applied to a reciprocating internal combustion engine; and

Figure 3 corresponds to Figure 2, but shows a gas turbine engine.

Referring to Figures 1 and 2 of the drawings, reference numeral 10 generally indicates a measuring apparatus in accordance with the invention.

The apparatus 10 measures twist in a drive shaft in the form of a crankshaft 30 (see Figure 2 of the drawings) of a reciprocating internal combustion engine 29. In Figure 2 only the pistons 32 of the engine, and connection of the pistons 32 via connecting rods 34 to cranks of a crankshaft 30 of the engine, are shown.

A flywheel 40 incorporating a ring gear having a plurality of circumferentially spaced teeth 42 is mounted at one end of the crankshaft 30. The flywheel 40 and specifically also the teeth 42 are of a magnetic material. During operation of the engine, thrust of the pistons 32 during power strokes causes twist in the crankshaft 30.

In order to measure said twist, the measuring apparatus 10 includes a circular metallic disc 50 secured to the end of the crankshaft 30 opposite the flywheel 40. The disc 50 has a plurality of formations or teeth 52 defining triggers in the form of datum points. The teeth, in this embodiment, are of magnetic material.

The apparatus 10 further includes a sensor in the form of a magnetic sensor or pick-up d vice 12.1, .g. Part No. 304166 from the RS catalogue, mounted on the engine adjacent a pitch circle of the teeth 52 of the disc so as to b registered sequ ntially with the t th as the disc 50 rotates with th crankshaft 30. Each time a tooth 52 is in r gister with the s nsor 12.1 a signal in the form

of a pulse is produced, and is conveyed to the apparatus 10 as shown at 13.1. The teeth define triggers in the form of datum points.

The apparatus 10 also includes a sensor in the form of a magnetic sensor or pick-up device 12.2, e.g. Part No. 304166 from the RS catalogue, mounted on the engine adjacent a pitch circle of the teeth 42 of the ring gear on the fly wheel 40 so as to be registered sequentially with the teeth as the flywheel 40 rotates with the crankshaft 30. Each time a tooth 42 is in register with the sensor 12.2, a signal in the form of a pulse is produced and is conveyed to the apparatus 10 as shown at 13.2. The teeth 42 define triggers in the form of measure points.

In another embodiment, the sensors 12.1, 12.2 may be optical sensors and the triggers 42, 52 may be optically detectable surfaces.

For convenience, the sensors 12.1, 12.2 or the signal outputs 13.1, 13.2 are shown at 12 in Figure 1.

As the crank shaft 30 rotates, when each datum point 52 passes the sensor 12.1, a signal pulse is generated and is recorded in a processor 14 (Figure 1) including a clock 18, thus setting a datum time moment. The clock 18 typically operates at a frequency of 10 MHz.

Assume the crank shaft 30 rotates under no load and at a rotational speed which is measured and recorded (conveniently in the processor 14 by means of the signal pulses generated by the sensor 12.1 on being passed by the datum points 52). Being under no load, the crank shaft 30 is under zero twist. The arrival time moments of the respective triggers 52 are sensed and are recorded as are the respective time periods between respective datum time moments and the respective arrival time moments - bearing in mind the rotational speed of the crank shaft 30. From this empirically derived data, computed arrival time periods, under no load conditions, can be computed by the processor 14 for any giv n or measured rotational sp ed. Advantageously, the number of datum points and th number of measure points are equal and they can then advantage usly be associated on a one-on-one basis. If the numb r of points are not th sam , each m asure point is associated with an appropriate or most

appropriate datum point, for example on the basis of minimizing the time periods.

When the crank shaft 30 rotates under load, the power strok s of the pistons 32 impart torque pulses to the crank shaft causing twist in the crank shaft. The amount of twist depends on physical characteristics of the crank shaft, e.g. effective moment of inertia and the torsional Young's modulus of the material of the crank shaft, the effective length over which the torque is applied (i.e. th longitudinal distance between the respective big end bearing and the flywheel 40), and the magnitude of the torque. All of the above except the magnitude of the torque remain constant for each piston 32, and can be pre-established for each engine or type of engine, advantageously empirically. Thus, the amount of twist uniquely defines the magnitude of the torque.

Furthermore, due to the twist, the respective triggers 42 arrive at the sensor 12.2 late relative to a respective computed arrival time moment. The amount of time lag, bearing in mind the rotational speed and the length over which the torque is transmitted, uniquely defines the twist.

The processor 14 is programmed to measure the respective time lags and to calculate the respective twists, as mentioned above, taking into account the rotational speed and the lengths over which the torque is transmitted, for th respective piston power strokes which are obtained from the firing order of the specific engine. From the calculated twist, the torque applied in each power stroke of each piston is calculated.

The apparatus 10 accordingly includes the processor 14 including a comparator 16 into which the respective signals are input from item 12.

Arrival time moments are compared by the comparator 16, from which the time periods are measured by the clock 18. Typically, the clock 18 operates at a frequency of 10 MHz, as mentioned above. The Applicants expect such resolution to be sufficient for purposes of this invention for use in commercial reciprocation engines.

Th tim periods ar compared and twist, and ultimately torqu values, are calculated as explained abov . Results are stored in a data storage

means 20, overwriting any previously stored value therein every second revolution in the case of a four-stroke engine.

The processor 14 further includes a second comparator 21 which includes a dataset prepared before installation and characterizing the engine when it is performing optimally. The dataset includes the optimum twist values or torque values in the crankshaft 30 for a wide range of speed and other conditions. The dataset is stored in the form of a regression equation. The comparator 21 compares torque output or a quantity related to torque as measured and calculated in accordance with this invention with a standard or reference value in the dataset. The comparator 21, and control 22 mentioned below, in combination with the processor 14, form an engine management apparatus in accordance with the invention.

Based on said comparison, a signal is generated and sent to a control 22, forming part of the apparatus 10. The control 22 is configured to control an operating function of the engine e.g. ignition timing for a spark ignition engine, injector timing in the case of a diesel engine, boost pressure in the case of a turbocharged or supercharged engine, and the like, thereby to optimize engine performance. Thus it is possible to dynamically control engine performance at the level of individual pistons based on measurement of twist or torque or related quantity in the crankshaft 30 of the engine.

By having large numbers of datum points and measure points, the frequency of measurement during a revolution of the flywheel 40 is high and as a result the torque output of each piston 32 can be resolved accurately.

Advantageously, the processor 14 is preprogrammed during processing to process the measured data, for example by making use of Fast Fourier Transforms, to ameliorate the effect of vibrations and resonances in reciprocating and rotating components of the engine on the measured data and thus to isolate or to isolate to a degree, information which is useful in the context of this invention.

Furth r, advantag ously, the engine management apparatus is preprogrammed, when th ngin is operated und r no l ad (for xampl when it

is idling), to calibrate the measuring apparatus in respect of datum time periods. This has, inter alia, the advantages that calibrating takes place r gularly and thus also compensates for changes in ambient conditions and engine conditions (e.g. ambient and engine temperatures).

The Applicants believe that it is an advantage of the invention that it provides a system for monitoring engine performance which makes use of magnetic sensors which produce a well defined signal, are relatively robust, and have a good service life considering the harsh operating conditions of an engine. Further, by making use of the teeth of the flywheel and teeth on a disc fast with the crankshaft as measure and datum points, the system can be manufactured cost effectively. Further, an advantage of the system is that it makes use of the time lag between the respective signals when the crankshaft 30 is under load relative to when it is under no load and is thus self-calibrating in that variations due to e.g. temperature effects, mechanical manufacture variations/tolerances etc. are compensated for. The Applicants believe that by optimizing engine performance in accordance with the invention, the toxic content of exhaust fumes may be reduced. A further advantage of the invention is that it provides a system for real time measuring twist in a crankshaft during operation of an engine and to control operating functions in real time of the engine thereby to optimize engin performance.

With reference to Figure 3, a gas turbine engine is generally indicated by reference numeral 129. The gas turbine engine is shown schematically, mainly in outline. The gas turbine engine 129 includes a main shaft 130 to which the current invention is applied. Conventionally, the gas turbine engine includes a low pressure compressor represented by one stage 132.1 thereof adjacent an inlet of the gas turbine engine, a high pressure compressor downstream of the low pressure compressor, a combustion chamber, turbine stages 132.3 and an outlet.

In accordance with the invention, twist of the main shaft 130 is m asured and torque is derived from the measured twist. These measurements and calculations ar ffect d in the same fashion as described with reference to Figur s 1 and 2 for the r ciprocating engine. Thus, also on the gas turbin engin , datum trigg rs 152 trigger a s nsor 112.1 to generate a signal. The triggers 152

are conveni ntly provided on r by turbine vanes toward a rear nd of the central shaft.

Furthermore, triggers are provided on or by the respective vanes of a first stage 132.1 of the low pressure compressor toward a front of the central shaft 130, and a sensor 112.2 is provided peripherally adjacent the pitch circle of the compressor vanes.

It is to be appreciated that stages other than the first stage of th low pressure compressor and the last stage of the turbine may be used to locat the triggers. Furthermore, it is to be appreciated that it is possible that a time lead as opposed to a time lag may be measured. For purposes of this invention a time lead is to be regarded as a negative time lag.

It is regarded as an important advantage that casings surrounding the compressor and turbine stages are of non-magnetic material, whereas th vanes are of magnetic material. Thus, the invention can be applied in a non-invasive manner, in so far as the sensors can be external of the casings.

It is to be appreciated that operation of a gas turbine engin approximates a steady state condition during any one revolution or small number of revolutions. Thus, first, torque fluctuations are expected to be substantially less than for a reciprocating engine. Thus, the Applicant envisages that a smaller number of triggers may be sufficient, also bearing in mind that, in gas turbine engines, very high speeds are sometimes used.

In other respects, performing the invention and the advantages obtained from the invention are substantially the same as explained with reference to Figures 1 and 2 in respect of the reciprocating engine.

CLAIMS

1. A method of measuring twist in a rotating shaft which is subjected to torque including sensing an arrival time moment of a measure point on the shaft at a fixed measure station, comparing the arrival time moment with a computed arrival time moment of said measure point at said measure station under a no load condition, measuring rotational speed of the shaft, and calculating the twist in the shaft on the basis of the time lag and the rotational speed.

2. A method as claimed in Claim 1 which includes sensing and recording a datum time moment when a datum point on the shaft, longitudinally spaced from said measure point by a predetermined distance, passes a fixed datum station, and measuring a measure time period between said datum time moment and said arrival time moment.

3. A method as claimed in Claim 2 which includes empirically predetermining a datum time period between a datum time moment and an arrival time moment under a no load condition at a determined rotational speed, and computing a computed time period and a computed arrival time moment for any specific rotational speed on the basis of the datum time period bearing in mind the respective rotational speeds.

4. A method of measuring twist in a rotating shaft which is subjected to torque, between a datum point on the shaft and a measure point on the shaft longitudinally spaced from the datum point, the method including

establishing a datum time period between a datum time moment the datum point passes a stationary datum station and a time moment the measure point passes a stationary measure station under a no load condition and recording rotational speed of the shaft as the datum speed;

measuring a measure time period between a time moment the datum point passes the stationary datum station and a time moment the measure point passes the stationary measure station when the shaft is subjected to torque, recording the rotational sp d of the shaft as the measure sp ed and stablishing longitudinal positions respectively at which torque is applied and of th datum point and of th measure point;

calculating the twist in th shaft from the difference between the measure

time period and the datum time period, bearing in mind the difference between the measure speed and the datum speed.

5. A method as claimed in Claim 4 in which a torque point at which torque is applied to the shaft and a load point at which a load is connected to the shaft are longitudinally spaced, the shaft being stressed and undergoing twist between the torque point and the load point, one of the measure point and the datum point being positioned along said stressed portion of the shaft, the other of the measure point and the datum point being positioned in a relaxed portion of the shaft beyond one of the torque point and the load point.

6. A method as claimed in Claim 5 in which the shaft is a crankshaft of a reciprocating internal combustion engine.

7. A method as claimed in Claim 6 in which the reciprocating engine includes a ring gear having gear teeth at one end of the crankshaft and a disc at an opposed end of the crankshaft, the datum point being on the disc, the measure point being on a gear tooth of the ring gear.

8. A method as claimed in Claim 7 which is performed in respect of a plurality of measure points and a plurality of datum points, the plurality of measure points being on a corresponding plurality of gear teeth of the ring gear and the plurality of datum points being points which are circumferentially spaced on the disc.

9. A method as claimed in Claim 8 in which the reciprocating internal combustion engine includes a plurality of cylinders, the method being performed in respect of each cylinder.

10. A method as claimed in Claim 8 or Claim 9 which is performed for each power stroke of the reciprocating internal combustion engine.

11. A method as claimed in Claim 5 in which the shaft is a main shaft of a gas turbin engine.

12. A method as claimed in Claim 11 in which at least one of the datum

point and the measure point is on a vane of at least one of a compressor and a turbine of the gas turbine engine.

13. A method as claimed in Claim 12 which is preformed in respect of a plurality of measure points and a plurality of datum points, the plurality of measure points being on a corresponding plurality of vanes of one of the compressor and the turbine and the plurality of datum points being on a corresponding plurality of vanes of the other of the compressor and the turbine, the sensors being external of casings surrounding respectively the compressor and the turbine.

14. A method as claimed in any one of claim 4 to Claim 13 inclusive in which establishing the time moments includes triggering a sensor at respectively the datum station and the measure station by means of triggers at correspondingly the or each datum point and the or each measure point, creating a signal by each sensor and recording the signal against time.

15. A method as claimed in Claim 14 in which the triggers are masses of magnetic material, and the sensors are responsive to said magnetic material to create said signals.

16. A method as claimed in Claim 14 in which the triggers are optically detectable surfaces, and the sensors sense passing of the triggers optically.

17. A measuring apparatus for measuring twist in a rotating shaft which is subjected to torque, the measuring apparatus including

at least one datum trigger at a datum point on the shaft;

a datum sensor at a stationary datum station arranged to sense said at least one datum trigger when said at least one datum point is in register with the datum station and to generate correspondingly at least one datum signal;

at least one measure trigger at correspondingly at least one measure point on the shaft longitudinally spaced from said at least one datum point;

a measure sensor at a stationary measure station arrang d to sense said at l ast one measure trigger when said at least one measure trigger is in register with the m asur station and to gen rate correspondingly at least on measure signal;

a clock ke ping time;

a rotational speed meter for measuring and recording rotational speeds of the shaft against time respectively as the datum spe d and as the measure speed;

recording means for recording said datum and measure signals against time;

a processor programmed to establish

correspondingly at least one datum time period between a time moment said at least one datum point passes the datum station and a time moment said at least one measure point passes the measure station under no load conditions and recording the rotational speed of the shaft as the datum speed,

correspondingly at least one measure time period between a time moment said at least one datum point passes the stationary datum station and a time moment said at least one measure point passes the stationary measure station when the shaft is subjected to torque and recording the rotational speed of the shaft as the measure speed, and

the twist of the shaft from the difference between said at least one measure time period and said at least one datum time period, bearing in mind the ratio between the measure speed and the datum speed.

18. A measuring apparatus as claimed in Claim 17 in which the shaft includes a torque point at which torque is applied to the shaft in use and a load point at which a load is connected to the shaft in use, the torque point and the load point being longitudinally spaced, the shaft, in use, being stressed and undergoing twist between the torque point and the load point, one of the or each measure point and the or each datum point being positioned along said stressed portion of the shaft, the other of the or each measure point and the or each datum point being positioned in a relaxed portion of the shaft beyond one of the torque point and the load point.

19. A measuring apparatus as claimed in Claim 18 in which the shaft is a crankshaft of a reciprocating internal combustion engine.

20. A measuring apparatus as claimed in Claim 19 which includes a plurality of measure points and a plurality of datum points.

21. A m asuring apparatus as claimed in Claim 20 in which th reciprocating engine includes a ring gear having gear te th at one end of the crankshaft and a disc at an opposed end of the crankshaft, th datum points and

the measuring points being respectively on gear teeth of the ring g ar and at circumferentially spaced positions on the disc.

22. A measuring apparatus as claimed in Claim 18 in which the shaft is a main shaft of a gas turbine engine.

23. A measuring apparatus as claimed in Claim 22 in which at least one of the datum point and the measure point is on correspondingly at least one of a vane of a compressor and a vane of a turbine of the gas turbine engine.

24. A measuring apparatus as claimed in Claim 23 which includes a plurality of datum points and a plurality of measure points, the datum points and the measure points being respectively on vanes of the compressor and the turbine.

25. A measuring apparatus as claimed in any one of Claim 17 to Claim 24 inclusive in which the triggers are masses of magnetic material, and the sensors are responsive to said magnetic material to generate signals.

26. A measuring apparatus as claimed in Claim 25 in which the sensors are in the form of magnetic sensors arranged external of casings surrounding respectively the compressor and the turbine.

27. A measuring apparatus as claimed in any one of Claim 17 to Claim 24 inclusive in which the triggers are optically detectable surfaces, and the sensors are optical sensors responsive to the optically detectable triggers to generate signals.

28. A method of measuring torque in a rotating shaft, including measuring twist in the rotating shaft in accordance with any one of Claim 1 to Claim 16 inclusive, and calculating torque on the basis of the measured twist bearing in mind a pre-established length of the shaft over which length said twist is measured, and pre-established physical characteristics of the shaft determining torque-twist b haviour of the shaft.

29. A method as claim d in Claim 28 in which said physical characteristics of the shaft determining torque-twist behaviour of the shaft are

established empirically.

30. A measuring apparatus for measuring torque in a rotating shaft, which includes a measuring apparatus for measuring twist as claimed in any one of Claim 17 to Claim 27 inclusive, in which the processor is programmed to calculate torque on the basis of the measured twist bearing in mind a pre-established length of the shaft over which length said twist is measured and pre-established physical characteristics of the shaft determining torque-twist behaviour of the shaft.

31. A method of managing operation of an engine including measuring a quantity related to torque in a drive shaft of the engine as claimed in any one of Claim 1 to Claim 16 or Claim 28 or Claim 29, comparing the measured value of said quantity related to torque to a predetermined standard value of said quantity, establishing any deviation between the measured value and the standard value and controlling an operating function of the engine in response to said establish deviation.

32. A method as claimed in Claim 31 in which said operating function of the engine is at least one of ignition timing when the engine is a spark ignition engine, injector pump timing when said engine is a diesel engine, boost pressure when said engine is turbocharged or supercharged.

33. A method as claimed in Claim 31 or Claim 32 including automatically calibrating the measuring apparatus in respect of datum time periods when th engine is operated under a no load condition.

34. An engine including

a measuring apparatus as claimed in any one of Claim 17 to Claim 27 or claim 30;

an engine management apparatus including a comparator arranged to receive a signal indicative of a measured value of a quantity related to torque in a drive shaft of the engine from the measuring apparatus, the comparator being preprogramm d to compare said measured valu with a standard valu of said quantity related to torque to g nerat a control signal, the engine management apparatus being responsive to said control signal to control an operating function

of the ngine.

35. An engine as claimed in Claim 34 in which said operating function of the engine is at least one of ignition timing when the engine is a spark ignition engine, injector pump timing when said engine is a diesel engine, boost pressure when said engine is turbocharged or supercharged.

36. An engine as claimed in Claim 34 or Claim 35 in which the engine management apparatus is preprogrammed to calibrate the measuring apparatus in respect of datum time periods when the engine is operated under a no load condition.

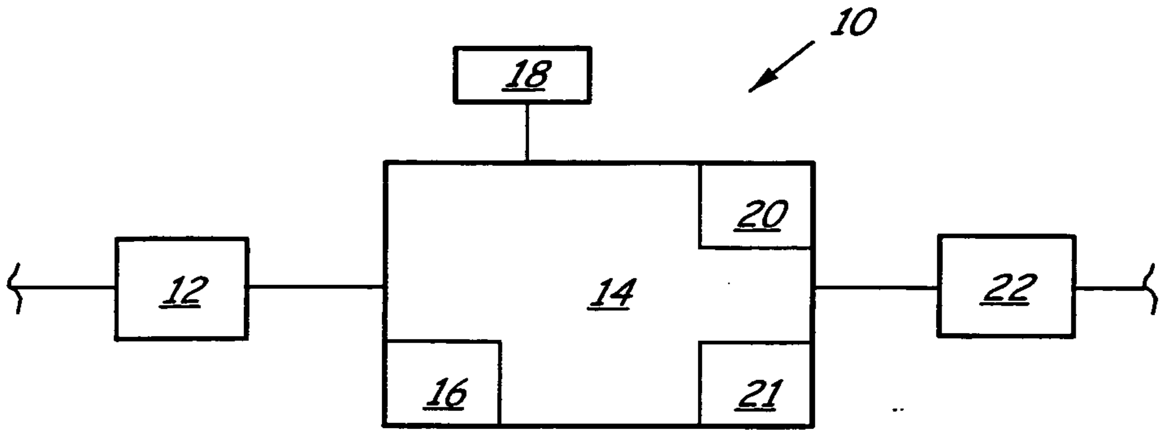


FIG 1

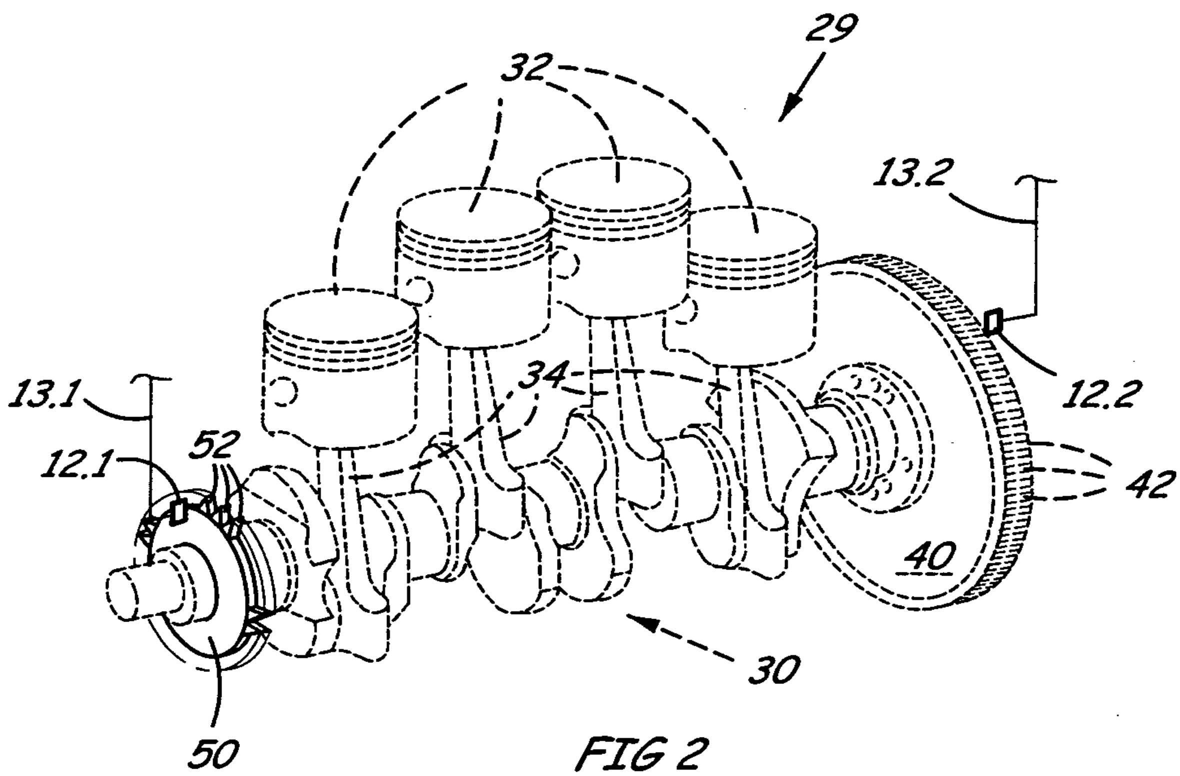


FIG 2

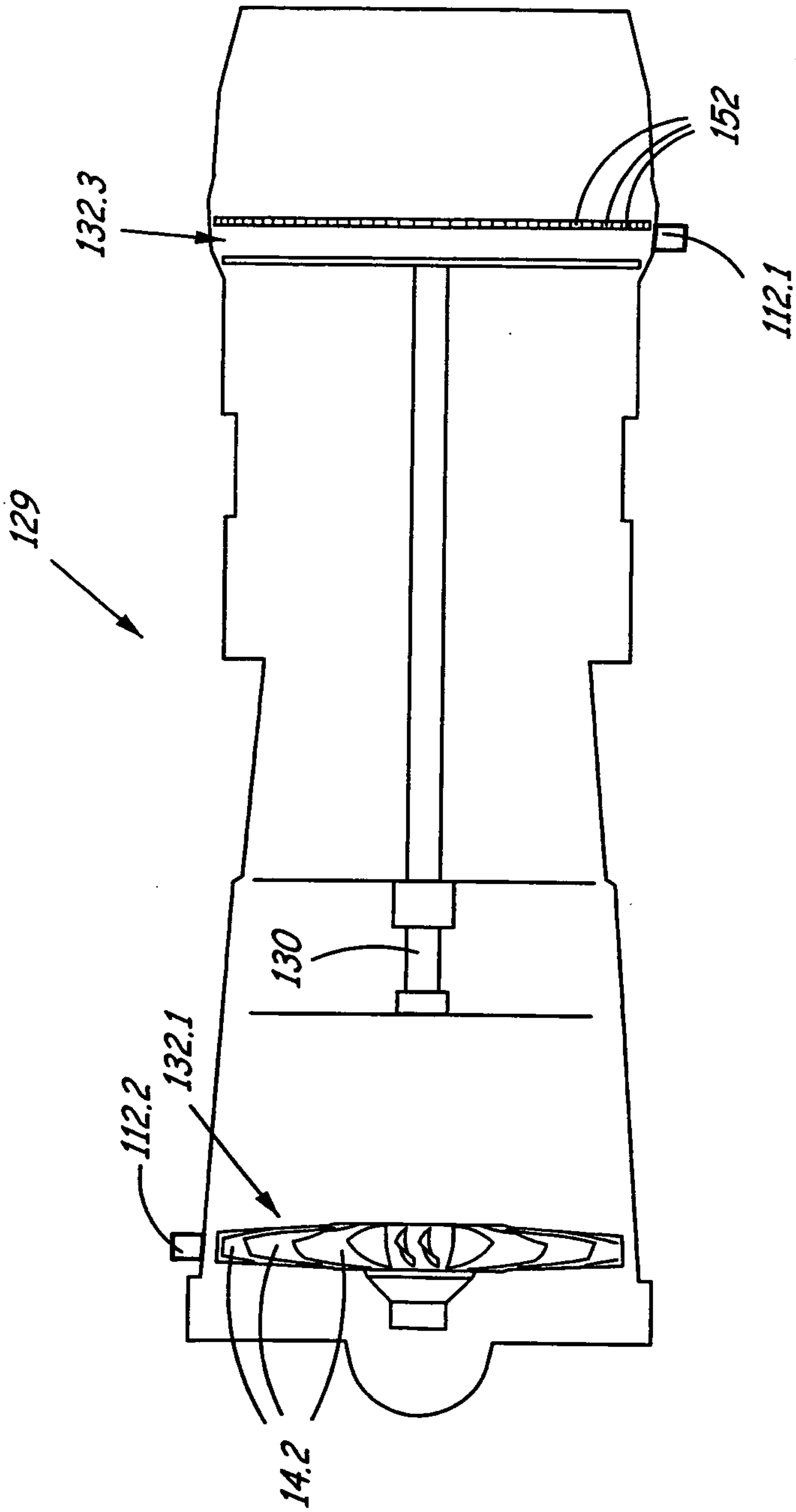


FIG 3

INTERNATIONAL SEARCH REPORT

Inter[illegible]l Application No
PCT[illegible] 00/00181

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01L3/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 20395 A (SIEMENS AG ;GLOGER MEINRAD (DE)) 4 July 1996 (1996-07-04)	1-5,11, 14-18, 22,25, 27,28,34
Y	the whole document	6-10, 30-32,35
Y	US 5 546 793 A (HUHN WERNER ET AL) 20 August 1996 (1996-08-20) abstract; figure 1	6-10, 30-32,35
X	US 4 627 297 A (AKIMOTO SHIGEYUKI) 9 December 1986 (1986-12-09) abstract; figure 1	1
X	US 4 995 257 A (LEON ROBERT L) 26 February 1991 (1991-02-26) the whole document	1-4,17

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 December 2000	05/01/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Zafiropoulos, N

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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